Concluding Remarks to Cosmic-Ray Symposium

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IN concluding this conference I have been asked by President Du Bridge to summarize its almost unsummarizable proceedings. I shall try only to make a few comments. What we have heard here, the arguments about the nature of the incoming cosmic radiation, the arguments about the origin of the incoming cosmic radiation, made a very deep impression; and so too the new evidence as to the kinds of particles which are found, evidence on which the theoretical physicist has learned to be properly humble. Apart from arguments which are almost arguments of consistency, and which make us hesitate to believe that those mesons that are easily produced by nuclei are hard for nuclei to capture, there are of course no *a priori* views at the moment about what the things may be. I think it hard to disbelieve Le Prince Ringuet's evidence for a very heavy meson.

But perhaps what to me was most exciting of all was the account from Schein and above all from Rossi about the nature of the interactions which are encountered in the cosmic radiation. It will be some time before one will be able to mock up the 10-billion volt nucleon-nucleon collisions, with which presumably the cosmic-ray story starts, by artificial acceleration. Here again the conclusion which one is first led to is somewhat surprising. One finds that as products of these collisions there are at least three kinds of radiation. There are, at least, nucleons; there are the cascade components, electrons, and gamma-rays, and there are mesons. The general energetic average over the cosmic-ray spectrum indicates that the amount of energy going into these three different components is not very different, one from the other. There may be, as Schein said, a strong tendency for the nuclear component to play a less prominent part as the energy of the collision is increased. We also know that the primaries lose their ability to make by collision the second and third components very early—essentially after a few nuclear impacts. A few passages in the neighborhood of the nucleus, and they can no longer do these things.

I think that the possibility should perhaps be faced that we not only don't know what the elementary particles are, but that the whole way of thinking about their interactions, which we have derived by analogy from electromagnetic theory, and by the application of this analogy to problems of the meson field as Yukawa originally suggested, that these views may be quite wrong. We have at the moment at least the possibility of trying further to exploit that analogy. One or two points about this: one is that a really good job to date has not been done. Heitler gladly told you that his theory was not a really good job. The really good job would be to take advantage, or rather, and this is the second point, to see whether one can take advantage of the developments in electrodynamics that are so much associated with Schwinger's name.

As you know, the purpose of these developments has been to take into account, certainly in an approximate way, and perhaps even in principle rigorously, the effects, on the one hand of the interaction of charges with the fluctuations in electromagnetic fields that derive from the quantum nature of light, and on the other, the interaction of quanta with fluctuations in charge that derive from the phenomena of pair production and annihilation. Schwinger's achievement has been to provide a method for isolating these "reactive" effects, which manifest themselves as peculiar deviations in the laws of interaction between electrons and between electrons and radiation, from the paradoxical effects expressing the contributions of these same interactions to the mass and charge of the elementary particles, contributions that are not, at least directly, measurable or separable from other sources on inertia or charge, and the infinite values of which, according to present theory, are thus not in themselves in contradiction with experience. In electrodynamics the alteration of interaction laws thus found is small; it is probable that, if completely evaluated, it would have the effect of making all real interactions less singular.

For the case of nucleons and mesons, arguments of analogy suggest that these reactive corrections would be far larger, and that their neglect could give a totally misleading picture of nucleon interactions and nucleon-meson collisions. It is not known whether if the very much more complicated of the nuclear problems, where neither the nature of the fields nor the interactions is known from classical physics, and where surely the interactions are in some way far stronger, this can logically be done—it is certainly not known with what techniques to do it. It is above all unknown whether it makes any sense to do it; that is, whether this is a step toward describing the real world. Perhaps that may be a point on which we shall have evidence for Dr. Millikan's next birthday. If it were necessary today to prejudge the outcome, perhaps we should doubt that the attempt to take into account that interactions between fields are here surely very large would in itself lead to a theory in agreement with experience.

If one tries in these problems to use only the roughest arguments of correspondence as to what to expect in high energy nucleon collisions, one comes, if he takes only known couplings into account, to a picture in some respects like that already outlined here by Heitler. Thus, for instance, one would see no appreciable chance for the emission of gamma-rays or electrons during the encounters. One then ascribes the fact that there obviously is a soft component produced by these encounters to the production of unstable mesons, whose decay produces the soft radiation. A natural view has seemed to be that we were dealing with unstable neutral mesons, the existence of which might give a sort of isotopic symmetry to nuclear forces. But, for instance, the Le Frince Ringuet mesons, if they were also strongly coupled to nuclear matter, would likewise be expected to disintegrate into gamma-rays; perhaps the one picture we have seen indicates a lifetime rather long to fit this supposition.

We have come to the view that probably, in the relatively high energy region, the number of mesons produced in nucleon impacts is typically greater than one, and that it increases slowly with the energy of the encounter. Heitler's failure to find this multiplicity may derive, in part from the special nature of the problems studied, but in the main, I believe, from the peculiarities of his treatment of radiation reaction. At least there are problems, where one knows the answer from classical electrodynamics, and where there is multiplicity of emission, and yet where the theory of Heitler would not give a correct account of it.

On the experimental side, I may mention two points that bear on the question of multiplicity, and that have been brought up in our meetings. One has to do with the course of the air shower curve, and more generally with the variation of the soft component, in the atmosphere. There has been work, notably by Lewis and by Christy and Mills, towards a theoretical understanding of what these curves would be like if we were dealing with a primary electron or primary photon. If in fact the photon or electron were made singly or in fixed small numbers by nucleon encounters, say, on the average, some fifty grams or so below the top of the atmosphere, the curves should be displaced downward correspondingly. Therefore we should expect the experimental air showers curves (and also those for the soft component) to have their maximum well below that calculated for a soft primary. According to the analyses of Lewis, and of Mills and Christy, this seems not be true. The maxima are definitely higher than calculated. This means that although the soft component is "late" in getting started, this is more than made up for by the initial multiplicity with which it starts, which must be considerably greater than the cascade multiplication in the thickness of matter needed on the average for a nucleon encounter.

The second point may be more speculative. In Auger's beautiful report he told us how close, in Auger showers, is the relation between the penetrating component on the one hand, the cascade component on the other. Even after filtration with 20 cm of Pb there are still components present capable of making cascades. If, as seems most reasonable, we are here no longer dealing with the fluctuations in the penetrating power of the high energy cascades per se, then this would fit rather closely with the suggested views about the nature of the primary collisions. In these collisions the primary would lose the greater part of its energy to mesons. Among these perhaps a third will be neutral and unstable and give rise to the cascade. The others will be charged mesons and penetrating, and will for the most part be distributed over an area at sea level of some hundred meters square. For high energies the rate of pi-mu-decay will be slowed, so that many mesons will retain their nuclear activity; they will be able to initiate cascades something like a nucleon cross section. This interpretation, however, uncertain at the moment, may deserve further study.

However that may be, all the basic questions seem to me quite open. It may be doubted whether these rough descriptions, exploiting points of supposed analogy between the Maxwell field and the Yukawa field, have any valid content; it may be doubted whether a refinement of such theory, based on a generalization of the recent advances in electrodynamics, will lead toward the truth; surely, if this refinement can be carried out at all in a logically consistent manner, it will lead to a theory rather radically different from what we have today. It may well be that a quite new description of interactions is called for, at present no more to be anticipated than the taxonomy of the mesons themselves.

On these questions experiment will throw light: what are the particles with which we have to deal? what are the primary collisions, what their immediate and what their secondary products? are they multiple? and if so, how do multiplicity and cross section vary with energy? what are the many origins of cascade radiation? what becomes of the mesons? . . . These are among the questions to which this conference has led us; the answers will be the elements of our understanding of the fundamental particles and the laws of their interaction.